Energy efficiency policy in a non-cooperative world[*]

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Abstract

In this paper, we explore energy efficiency policies in the presence of a global environmental problem and international cost interdependency associated with R&D activities. We develop a simple model with two regions where the cost of an appliance in one region depends upon the level of energy efficiency in that region and the level of R&D activities by the appliance industry. In our model, the cooperative outcome can be decentralized by imposing a tax on energy. However, we show that when regions do not cooperate, they have an incentive to adopt additional instruments to increase energy efficiency. The reason is that the lack of cooperation leads to under-taxation of the environmental externality which in turns creates an incentive to try to reduce emissions produced abroad. We illustrate this phenomenon with the Californian vehicle greenhouse gas standards.

Keywords

Energy efficiency policies; innovation; cost interdependencies; energy tax; fuel efficiency standard; climate changes

JEL code: O38, Q48, Q54, Q58, R48

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I. Introduction

In most developed countries, there is a long standing tradition of public policies designed to improve energy efficiency. Energy efficiency standards are prime examples of such policies. Wiel and MacMahon (2003) survey the experience with different types of energy efficiency standards for appliances and report how the first standards were set in France in the sixties for refrigerators and freezers. For the US, they report the experience in the seventies with Californian standards for refrigerators. For cars, one of the most important energy using appliances, the US has its fuel efficiency standards since 1975. Climate change concerns and surging oil prices have renewed interest in energy efficiency. The EU (CEC, 2006) has committed to a 20% energy saving objective in 2020 and plans to introduce minimum energy performance standards for a wide array of products ranging from boilers to washing machines. For new passenger cars the EU (CEC, 2009) has opted for a 120g of CO_2 fleet average standard. In 2009, the US has strengthened their Corporate Average Fuel Efficiency Standard (CAFE), requiring that new cars and light trucks meet a fleet wide average of 35.5 miles a gallon by year 2016. In 2006, Japan increased the stringency of its fuel economy standards, first adopted in 1999.[1]

Beside standards, tax incentives have also been introduced to increase the demand for energy efficient appliances. For example, several jurisdictions have introduced fiscal measures taxing inefficient vehicles and/or providing tax rebates on efficient cars (e.g. gas guzzler tax, rebate for hybrid cars etc.). Subsidies are also sometimes used to

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[1] For an international comparison of fuel economy regulations see Feng *et al.* (2007).

accelerate the retirement of older inefficient appliances (e.g. cash for clunkers programs, refrigerator and freezer recycling programs). Also, most jurisdictions offer incentives to stimulate R&D activities in this area.

Measures to boost energy efficiency of appliances are generally considered by economists as a second best policy. They recommend instead increasing energy taxes in order to internalize the external costs associated with energy use.[2] They point to the wider leverage of an energy tax as it affects not only the design of the appliance but also the intensity of use. For example, Austin and Dinan (2005) show that it is possible to achieve the same 10% reduction in the US gasoline consumption at a cost 58% to 71% lower by increasing the gasoline tax rather than by tightening the CAFE standards. Furthermore, contrary to an energy tax, improving the energy efficiency of an appliance may stimulate usage by lowering operating costs thereby reducing the policy effectiveness. Proponents of energy efficiency policies motivate their choice by informational failure and the need to correct consumers' myopia or loss aversion in selecting appliances (Greene et al. 2005, Greene et al. 2009). However, it is widely agreed that political reasons best explain the recourse to energy efficiency policies as political support for raising energy taxes is often very limited (Portney et al. 2003).

If political considerations may be the main driver, we show in this paper that the lack of cooperation between governments may also help explain why additional instruments besides an energy tax are often used. We develop a simple model with two regions that are assumed to be linked through a global environmental externality caused

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[2] Incentive for R&D activities may obviously also be justified if there are pure knowledge spillovers and subsidies for new equipment may be needed to overcome the learning by doing spillovers (Fisher and Newell, 2008).

by energy consumption and cost interdependency through R&D activities. More precisely, our model allows consumers to choose the level of use of an energy consuming appliance while an integrated manufacturer designs and sells appliances in both regions. The manufacturer also invests in R&D activities which reduces costs in both regions. In our model, there is only one distortion namely the environmental degradation. Indeed, in order to keep the analysis focused, we exclude other distortions such as market power or innovation spillovers. The first best outcome can therefore be decentralized by using only one instrument namely a tax on energy that internalized the environmental cost. Yet we show that when regions do not cooperate they have an incentive to use additional instruments besides the energy tax. The reason is simple: the lack of cooperation leads each region to impose a tax on energy that is too low ignoring the impact of its emissions on foreigners. This, in turn, favors the adoption of instruments designed to stimulate innovations so as to improve energy efficiency abroad thereby reducing the domestic environmental damage caused by foreign emissions. The additional instrument may be a subsidy on R&D. Other instruments such as a tax on appliances based on their energy rating or the imposition of efficiency standards may be used instead if R&D subsidies are not possible or too costly. We show, for example, that the imposition of a strict standard in one region may lead to the adoption of a more ambitious standard abroad when there is cost interdependency generated by R&D. We illustrate the relevance of this phenomenon using the Californian standards on GHG emission limits for motor vehicles.

The paper is organized as follows. In section II, we describe the model to analyse energy efficiency policies with cost interdependency. In section III, we examine the use of taxes on appliances based on their energy rating and efficiency standards for reducing foreign emissions. We also develop an illustration based on the Californian experience with GHG emission standards for cars. We conclude in section IV.

II. Energy Efficiency Policies with Cost Interactions

The Model

Consider a world with two regions denoted by superscript i=1,2 and each populated by n^i agents each owning one energy consuming appliance. We assume that all agents are similar and have utility function:

$$U^i = u(x^i, m^i) - E(F) \qquad (1)$$

x^i is the quantity consumed of a general consumption good and m^i the level of use of the appliance.[3] $E(F)$ represents the disutility associated with global pollution generated by appliance use, say climate change. It is increasing with worldwide energy consumption $F = F^1 + F^2$ with $F^i = n^i m^i g^i$, where g^i is energy consumption per unit of appliance use (we also call it energy consumption rate). U^i is assumed to be a well behaved utility function.

We assume that the cost of appliances in region i is given by $c^i(g^i, R)$ with $c^i_{g^i} = \frac{\partial c^i}{\partial g^i} < 0$ and $c^i_{g^i g^i} = \frac{\partial^2 c^i}{\partial g^i \partial g^i} > 0$. In other words, energy efficiency can only be improved (*i.e.* **lowering** g^i) by progressively installing more costly energy saving technologies. This is a common hypothesis in the literature which is backed by factual

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[3] For a vehicle, *m* would be the distance driven. For another appliance such as air conditioning, *m* may be the number of hours of use.

evidence.[4] The cost of an appliance is also determined by R the level of R&D activities realized by the appliance manufacturer. We assume that R&D activities lowers the cost of producing an appliance $c_R^i = \frac{\partial c^i}{\partial R} < 0$ but that the return is declining ($i.e.\, c_{RR}^i = \frac{\partial^2 c^i}{\partial R \partial R} > 0$). Moreover, R&D activities lower the marginal cost of improving energy efficiency meaning that $c_{g^i R}^i = \frac{\partial^2 c^i}{\partial g^i \partial R} > 0$. Of course as demonstrated by Knittel (2012), there is a trade-off in product characteristics and the opportunity costs of R&D efforts are here understood to include the specific efforts for fuel efficiency and also the cost of giving up improvements in other appliance dimensions. Also note that there is no subscript on the variable R since we assume that the appliance manufacturer is integrated meaning that it produces appliances for both regions.

The Coordinated Outcome

In a fully coordinated context, a social planner would try to maximize the sum of the utility of the citizens of both regions under a resource constraint. Formally,

$$Max \quad \sum_{i=1}^{2} n^i\big(u\big(x^i, m^i\big) - E(n^1 m^1 g^1 + n^2 m^2 g^2)\big) + \gamma\big[\big(\sum_{i=1}^{2} n^i\big(y - x^i - c^i\big(g^i, R\big) -$$

$$pmigi{-}R \qquad (2)$$

$$wrt\ x^i, m^i, g^i, \gamma, R$$

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[4] For the case of cars, National Research Council (2002) reviews several emerging technologies for improving automobile fuel rating (*e.g.* cylinder deactivation, aero drag reduction, 42 volt electrical systems) and evaluates their expected cost. Based on this review, incremental cost curves as a function of fuel rating are constructed for different vehicle types. These curves are decreasing and convex as we assume in our model.

The price of x is normalized to one while p, the resource cost of energy, is assumed to be exogenous. y stands for the per capita quantity of resources available in each region. After dividing by n^i, the first order conditions for x^i , m^i, g^i and R become:[5]

$$u_{x^i} - \gamma = 0 \quad (3)$$

$$u_{m^i} - (n^i + n^j)E_F g^i - \gamma p g^i = 0 \quad (4)$$

$$(n^i + n^j)E_F m^i + \gamma \left(c^i_{g^i} + pm^i\right) = 0 \qquad (5)$$

$$n^i c^i_R + n^j c^j_R + 1 = 0 \qquad (6)$$

with *i*=1,2.[6]

The interpretation of these conditions is standard and involves the balancing of marginal social benefits and costs. For example, conditions (5) state that the energy efficiency of the appliance owned by an agent in region *i* should be lowered so that the marginal cost increase for that agent ($-c^i_{g^i}$) is equal to the resulting marginal social benefit of this reduction. The marginal benefit has two components. First, the increased energy efficiency lowers the agent energy consumption by m^i, which reduces the environmental disutility of all agents ($\frac{(n^i+n^j)E_F}{\gamma}$). Second, the agent's energy costs are reduced by pm^i. Condition (6) states that the marginal benefit of R&D activities - the reduction of appliance costs in both regions - should equal the marginal cost of innovation (which is one).

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[5] A subscript indicates a partial derivate so that, for example, E_F represents the derivative of E with respect to F.

[6] To be concise, we do not repeat the resource constraint which is obviously also part of the first order conditions.

The policy that can decentralize this outcome will depend upon the timing of the game played and how consumers and the industry act. We assume a two-stage game where the social planner sets its policy instrument first; next consumers and the manufacturer take their decisions. As usual, we assume that the number of individuals is so large that they completely ignore the impact of their decisions on the global environment (*i.e.* they consider F to be exogenous). The environmental cost needs therefore to be internalized by a tax on energy. In such setting, region i's consumers solve the following problem:

$$Max\ u(x^i, m^i) - E(F) + \delta^i\left(y - x^i - q^i - (p + t^i)m^i g^i\right) \qquad (7)$$

$$wrt\ x^i, m^i, \delta^i$$

with q^i the appliance price and t^i the energy tax rate. The first order conditions are:

$$u_{x^i} - \delta^i = 0 \qquad (8)$$
$$u_{m^i} - \delta^i(p + t^i)g^i = 0 \qquad (9)$$

On the supply side, we assume, as mentioned above, that an integrated appliance manufacturer is serving both regions thereby eliminating the issue of under-investment in R&D due to innovation spillovers. Furthermore, we assume that there is no distortion on price or design associated with market power.[7] These simplifications are not essential for our results but they greatly help clarify the effects we want to highlight by disentangling them from other well-known forces. $g^i$and R are thus assumed to be chosen by the manufacturer so as to minimize the total cost of buying and operating the appliances (including the R&D cost) on the two markets (*i* and *j*) that it serves. Formally,

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[7] For the impact of market power on the appliance market see Fisher (2005).

$$Min\, n^i\left(c^i\left(g^i,R\right)+\left(p+t^i\right)g^i m^i\right)+n^j\left(c^j\left(g^j,R\right)+\left(p+t^j\right)g^j m^j\right)+R \qquad (10)$$

$$wrt\ g^i, g^j, R$$

The corresponding first order conditions are:

$$n^i\left(c^i_{g^i}+(p+t^i)m^i\right)=0 \quad (11)$$
$$n^j\left(c^j_{g^j}+(p+t^j)m^j\right)=0 \quad (12)$$
$$n^i c^i_R+n^j c^j_R+1=0 \quad (13)$$

Furthermore, the price charged to a consumer equals the average cost *i.e.*

$$q^i=c^i\left(g^i,R\right)+\frac{1}{n^i+n^j}R \quad (14)$$

so that the manufacturer profit is zero.[8] Once again the effects we want to highlight do not rest upon these simplifying hypotheses. We discuss this point further in our conclusions.

Matching conditions (3) to (6) with conditions (8),(9),(11) and (13) and using (14) we can show that setting

$$t^i=\frac{(n^i+n^j)E_F}{\gamma} \quad (15)$$

decentralizes the coordinated outcome. This energy tax leads to the optimal level of use and energy efficiency of the appliance. As there is only one externality, an energy tax is sufficient. We show however in the next section that a more complex energy efficiency policy is likely to emerge when regions do not coordinate.

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[8] Note that in our setting the fact that the price of an appliance is superior to the marginal cost does not create a distortion since the number of appliances is fixed (one per consumer).

The Uncoordinated Outcome

We examine the situation where there is no coordination in the policies of the two regions. Again, we assume a two-stage game with both governments simultaneously setting their policy instruments at the first stage. At the second stage, agents take their consumption and production decisions based on the first stage policy parameters. This game can be resolved by backward induction by first deriving stage two optimal decisions as functions of the policy instruments and then using this solution to solve stage 1. However, it is more revealing to examine region *i*'s optimal decentralization targets for x^i, m^i, g^i, R when it takes into account that its choice of R is going to affect F^j via stage 2 manufacturer's decision on g^j and region *j*'s consumers decision on m^j.[9] Remember that there is only one level of R chosen by the multinational firm that is affecting production cost in both region appliances. So we have:

$$Max\, u(x^i, m^i) - E\Big(n^i m^i g^i + F^j(R)\Big) + \rho^i \Big[\Big(y - x^i - c^i(g^i, R) - pg^i m^i) - \frac{1}{n^i+n^j}R\Big)\Big]$$

with $F^j(R) = n^j m^j(R) g^j(R)$ (16)

After some manipulations, the first order conditions become:

$$u_{x^i} - \rho^i = 0 \qquad (17)$$

$$u_{m^i} - E_F n^i g^i - \rho^i p g^i = 0 \qquad (18)$$

$$\frac{E_F n^i m^i}{\rho^i} + c^i_{g^i} + pm^i = 0 \qquad (19)$$

$$\frac{E_F}{\rho^i}\frac{\partial F^j}{\partial R} + c^i_R + \frac{1}{n^i+n^j} = 0 \qquad (20)$$

By matching (18) with (9), we obtain that region *i* imposes a tax on energy

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[9] In fact, g^j and m^j as functions of R are obtained as solutions to the equivalence for region *j* of equations (8), (9) and (12). These functions correspond to region *j*'s best response to *R*.

$$t^i = \frac{n^i E_F}{\rho^i} \qquad (21)$$

This tax rate is lower than the coordinated case (compare (21) with (15)) as government *i* only internalizes the environmental damage to its citizens. In other words, it ignores the environmental impact of its citizens' energy consumption on foreigners. This tax also insures that condition (19) matches condition (11). We see that the governments' targets in the non-coordinated case are not only different for the level of use of the appliance but also for the desired target for the R&D effort *R*. Comparing (20) with (13) helps to understand the different incentives for setting *R*. First, the manufacturer takes into account the marginal benefits of R&D in reducing the cost of cars in both regions while region *i* only cares about its own citizens. Second, the cost of R&D is averaged over the two regions and the price increase in the other region is not of a concern for the region interested in pushing for more R&D. There is a third difference which results from the impact of *R* on the foreign level of fuel consumption. Indeed, region *i* has an extra incentive to increase *R* if this leads to a decline in foreign emissions as shown by the first term in (20) (*i.e.* if $\frac{\partial F^j}{\partial R} < 0$). In other words, the lack of coordination between regions results in under-taxation of the environmental externality which, in turns, favours the adoption of policies to stimulate innovation so as to reduce emissions abroad.

Concerning the sign of the effect of *R* on the level of foreign emission F^j, note that:

$$\frac{\partial F^j}{\partial R} = n^j \left(\frac{\partial m^j}{\partial R} g^j + m^j \frac{\partial g^j}{\partial R} \right) \quad (22)$$

An increase in *R* clearly favours improvement in energy efficiency as $c^j_{g^j R} > 0$.

However, the overall impact also depends upon how m^j is affected by *R*. While the reduction in operating cost stimulates usage (rebound effect), the increase in ownership cost needs also to be taken into account.

Innovation can be stimulated via a subsidy on R. However, a subsidy may be difficult to justify if, for example, all the R&D activities are located abroad. Alternatively, a region may adopt policies to increase domestic demand for energy efficiency taking into account that, by stimulating R&D, foreign emissions may be lowered. We examine this possibility in the next section.

III. Policies to increase energy efficiency

In this section, we simplify further the model by assuming that i) the environmental damage is linear in the quantity of energy consumed *i.e.* wF with w the per capita environmental cost of one unit of energy, ii) both regions have an identical number of agents ($n^i = n^j = n$), iii) the use of the appliance is no longer a decision variable ($m^i = m^j = m$), iv) the preferences are log-linear in *x* and v) a subsidy on R&D is not possible because monitoring R&D activities of multinational firms is difficult. With these hypotheses, each region's objective boils down to minimize the sum of the environmental damage for the citizens of the region, the cost of producing appliances and their energy costs. First, we examine the recourse to a taxτ^i on the appliance energy rating g_i. Next, we analyse the use of energy efficiency standard (*i.e.* $g^i \leq g_s^i$). This last case also serves as a basis for the numerical example illustrating the Californian experience.

In this simplified model, the energy efficiency of the appliance in both regions and the level of R&D are set by the manufacturer so as to minimize:[10]

$$Min\ (c^1(g^1,R)+pmg^1+\tau^1 g^1)+(c^2(g^2,R)+pmg^2+\tau^2 g^2)+R \qquad (25)$$

$$wrt\ g^1,g^2,R$$

Solving this problem provides the equilibrium values as a function of the tax rate in each region: $g^1(\tau^1,\tau^2)$, $g^2(\tau^1,\tau^2)$ and $R(\tau^1,\tau^2)$. By differentiating the first order conditions, it can easily be shown that the level of energy efficiency in both regions increases with τ^i ($\frac{\partial g^i}{\partial \tau^i}<0$ and $\frac{\partial g^j}{\partial \tau^i}<0$) and so do innovation activities ($\frac{\partial R}{\partial \tau^i}>0$).

At stage 1, each region sets its tax rate by minimizing the total social cost of the appliance and taking into account the industry reaction at stage 2. Formally:

$$Min\ c^i\big(g^i(\tau^i,\tau^j),R(\tau^i,\tau^j)\big)+pmg^i(\tau^i,\tau^j)+\ wmn\big(g^i(\tau^i,\tau^j)+g^j(\tau^i,\tau^j)\big)+\frac{1}{2n}R(\tau^1,\tau^2) \qquad (26)$$

The first order condition is:

$$-\left(pm\frac{\partial g^i}{\partial \tau^i}+wmn\left(\frac{\partial g^i}{\partial \tau^i}+\frac{\partial g^j}{\partial \tau^i}\right)\right)=c^i_{g^i}\frac{\partial g^i}{\partial \tau^i}+c^i_R\frac{\partial R}{\partial \tau^i}+\frac{1}{2n}\frac{\partial R}{\partial \tau^i} \qquad (27)$$

Each region balances the marginal social benefit associated with stimulating the demand for energy efficiency with the marginal social cost. As before, the marginal benefit corresponds to the sum of the fuel expenditure saving and the reduction in environmental damage linked to domestic emission reduction. However, in this context, the government

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[10] Note that in this setting the tax on g^i is equivalent to a tax on energy since m is exogenous.

also takes into account that the domestic tax by stimulating innovation helps reducing foreign emissions ($i.e.\ wmn\frac{\partial g^j}{\partial \tau^i}$). The marginal social cost corresponds to the appliance cost increase taking into account the net effect of innovation.

Rather than taxing appliances based on their energy consumption rate, the different governments impose instead efficiency standards. With this policy instrument, one region cannot hope to reduce foreign emissions if both regional standards are binding and standards are set simultaneously as we have assumed so for. Indeed, at stage 2, the appliance manufacturer only decides on the optimal innovation effort given the imposed standards $R(g_s^i, g_s^j)$.[11] At stage 1, each region sets its standard anticipating what the foreign government will decide. In other words, region i's standard decision does not directly affect stage 2 level of emissions abroad (i.e. $wnmg_s^j$ is not a function of g_s^i when region *i* determines its standard).

However, things are different if governments set their standards sequentially. Suppose that region 1 decides its efficiency standard before region 2. Once the standards are imposed (stage 3), the manufacturer determines its R&D effort by minimizing the total cost of appliance production and operation:

$$Min\, n(c^1(g^1,R) + pmg^1) + \, n(c^2(g^2,R) + pmg^2) + R \qquad (28)$$

$wrt\ R$

subject to the constraints: $g^1 \leq g_s^1\ and\ g^2 \leq g_s^2$ with g_s^i the energy efficiency standard imposed by region i.

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[11] To keep the analysis focused, we do not model here the possibility for manufacturers to shift sales across models of different energy ratings (see for example Holland *et al.* 2009).

With the constraints binding, the first order condition is:

$$nc_R^1 + nc_R^2 + 1 = 0 \qquad (29)$$

which leads to the optimal R&D investment as a function of the standards $R^*(g_s^1, g_s^2)$.

Totally differentiating (29), we obtain that stricter standards do lead to more R&D:

$$\frac{dR^*}{dg_s^i} = -\frac{c^i_{Rg_s^i}}{c_{RR}^i + c_{RR}^j} < 0 \qquad (30)$$

At stage 2, region 2's government determines its standard by minimizing the following objective function:

$$Min \;\; c^2\big(g_s^2, R^*(g_s^1, g_s^2)\big) + pmg_s^2 + wmn(g_s^1 + g_s^2) + \frac{1}{2n} R^*(g_s^1, g_s^2) \qquad (31)$$

$$wrt \; g_s^2$$

The first order condition is:

$$c^2_{g_s^2} + c^2_{R^*} \frac{\partial R^*}{\partial g_s^2} + pm + wnm + \frac{1}{2n} \frac{\partial R^*}{\partial g_s^2} \;= 0 \quad (32)$$

This condition implicitly defines the best response function $g_s^2(g_s^1)$. Assume that the changes in the curvature of the cost function can be ignored (*i.e.* the third derivatives of the cost function are negligible), we can show that:[12]

$$\frac{dg_s^2}{dg_s^1} = -\frac{1}{D} \frac{\partial R}{\partial g_2^1} \left(\frac{c^2_{g_s^2 R}\, c_{RR}^1}{c_{RR}^1 + c_{RR}^2} \right) > 0 \quad (33)$$

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[12] If the second order conditions for a minimum are respected then *D* is positive.

This means that a stricter standard by region 1 favours the adoption of a more stringent standard in region 2. At stage 1, region 1 sets its standard so as to minimize:

$$Min\ \ c^1\left(g_s^1, R^*(g_s^1, g_s^2(g_s^1))\right) + pmg_s^1 + wmn(g_s^1 + g_s^2(g_s^1)) + \frac{1}{2n}R^*(g_s^1, g_s^2(g_s^1))\ (34)$$

$$wrt\ g_s^1$$

The first order condition is:

$$wnm + pm + wmn\frac{\partial g_s^2}{\partial g_s^1} = -\left(c_{g_s^1}^1 + \left(c_{R^*}^1 + \frac{1}{2n}\right)\left(\frac{\partial R^*}{\partial g_s^1} + \frac{\partial R^*}{\partial g_s^2}\frac{\partial g_2^s}{\partial g_s^1}\right)\right)\ (35)$$

Based on (35), we note that region 1's standard should be set so that the sum of the marginal environmental benefit of domestic energy reduction ($MEB^d = wnm$), the marginal energy cost saving ($MECS = pm$) and the marginal environmental benefit resulting from the follower's reaction ($MEB^f = wmn\frac{\partial g_s^2}{\partial g_s^1}$) equal the marginal cost imposed by the standard via higher appliance cost taking into account all the effects on R&D. As before, we find that cost interactions allow government 1 to have an impact on foreign emissions. In this case however, government 1 is affecting region 2's emissions via government 2's policy decision. The general mechanism is however quite similar. Obviously, this result depends, as always with strategic games, on the credibility of the commitment taken by the first mover. We discuss this issue further in the California context.

Illustration

To illustrate the relevance of the marginal environmental benefit abroad (MEB^f), we develop a simple numerical example based on the Californian car standards and their potential impacts on the rest of the US and Canada. Its purpose is not to provide a comprehensive and detailed numerical simulation but rather to provide a useful computation of how the impact on energy efficiency abroad may be relevant. In 2004, California imposed a unilateral 30% reduction in GHG emission rates by 2016. While the standards vary by type of vehicles and allow reducing GHG emission rates via improvements in air conditioning systems, the *California Air Resources Board* (2008) estimates that they would raise the average fuel efficiency of the fleet from about 25.1 to 35.7 MPG or equivalently reduce the fuel consumption rate from 3.98 to 2.8 gallons per 100 miles. In the California Global Warming Solution Act of 2006 (best known as AB-32), it is argued in Chapter 2, section (d) that *"…actions taken by California to reduce emissions…will have far-reaching effects by encouraging other states, the federal government, and other countries to act".* This quotation suggests that Californian standards are in part justified or, at least, influenced by the willingness to have an impact on public policies (and thus emissions) in the rest of the world. In fact, before the CAFE standards were strengthened to the Californian targets in early 2009, as much as 16 US States and Canadian Provinces had pledged that they would also adopt the California standards.[13] Section (e) of AB-32 hints at one of the ways California expects to influence the rest of the world: *"More importantly, investing in the development of innovative and pioneering technologies…will provide an opportunity for the state to take*

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[13] The Canadian government has also announced it would adjust its standards to the new CAFE targets.

a global economic and technological leadership role in reducing emissions of greenhouse gases".

To simplify the illustration, assume that the Californian standards have no impact on driving distance or on the number of vehicles. Based on our simplified model, the standard should be set so that the sum of MEB^d, *MECS* and MEB^f equals the marginal cost *MC*. We evaluate these four components in annual and per capita terms. Based on Fisher *et al.* (2007), the price increase of a vehicle associated to the reduction of the fuel consumption rate may be approximated by:

$$213 + 1941(\bar{g} - g)$$

with $\bar{g}$ being the initial level of the fuel consumption rate (in our case $\bar{g}$ =3.98). Assuming that vehicles last for 14 years, government uses a social discount rate (*r*) of 5% and given that in the US the number of cars per capita is about 0.8 (Harrington, 2008), the per capita marginal cost of reducing *g* is approximately:[14]

$$MC = 16 + 150(\bar{g} - g).$$

For *MECS*, we use a Californian annual driving distance of 8,015 miles (Federal Highway Administration, 2005) and a 2004 average price of gasoline net of taxes in California of 1.59$ per gallon.[15] The total reduction in fuel expenditure is thus given by $1.59\,x\,80.15\,(\bar{g} - g)$, implying a *MECS* constant at 127$.

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[14] We multiply the vehicle price increase by 0.8 x (1-d)/(1-d^{14}) with d=1/(1+r).

[15] Based on the *California Energy Commission*, the 2004 yearly average price of gasoline was 2.12$ per gallon so that the price net of taxes was about: 2.12/1.08 (sales taxes of 8%) minus the federal and state excise taxes of 0.364$.

For MEB^d and MEB^f, we only consider climate changes as it is one of the motivations behind the Californian initiative and we once again assume that environmental damage is linear in the quantity of fuel consumed. Based on (35), we therefore have:

$$MEB^d = wn^{Cal}m^{Cal} \text{ and } MEB^f = wn^{RUSC}m^{RUSC}\frac{\partial g^{RUSC}}{\partial g^{Cal}}$$

with w the constant per capita environmental damage generated by one gallon of gasoline. *Cal* stands for California and *RUSC* for rest of the US and Canada. For the population figures, we use n^{Cal}=36 millions and n^{RUSC}=300 millions and for the mileage per capita (expressed in 100 miles) m^{Cal}=80.15 and m^{RUSA}=100 (Federal Highway Administration, 2005). Following Fisher *et al.* (2007), we assume a value of 50$ per ton of CO_2 implying a damage of 12 cents per gallon of gasoline. This is the **worldwide** damage produced by one gallon of gasoline. If we assume that damages are equally distributed across the world, the damage per capita is therefore a meagre 0.12$/6.6 billions! In fact, if we use this last figure for w, MEB^d is negligible.[16] Furthermore, even with $\frac{\partial g^{RUSC}}{\partial g^{Cal}} = 1$, MEB^f is also very small. From these simple computations, we derive a first observation: *California somehow needs to take into account more than the domestic damage of climate change if we want climate change to be a significant factor affecting the stringency of the standards it imposes.*

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[16] The same conclusion holds if we assume that the damages are equally distributed *per dollar of income* (rather than *per capita*) across the world.

Therefore let us assume that California's objective is to minimize the worldwide climate change damage plus the private cost of cars in California. MEB^d and MEB^f become:[17]

$$MEB^d = 0.12\, m^{Cal} \text{ and } MEB^f = 0.12 \frac{n^{RUSC}}{n^{Cal}} m^{RUSC} \frac{\partial g^{RUSC}}{\partial g^{Cal}}$$

If $\frac{\partial g^{RUSC}}{\partial g^{Cal}} = 0$, $MEB^f = 0$, MEB^d is 9.6$ which combines with *MECS* and taking into account *MC*, justifies a standard of 3.18 gallon per 100 miles. This leads to our second observation: *if Californian standards have no impact on fuel efficiency elsewhere, climate change concerns only marginally affect the standard*. Indeed, compared to a fuel rating based on *MFCS* exclusively, MEB^d increases the stringency of the standard by less than 3%.[18]

At the other extreme, suppose that $\frac{\partial g^{RUSC}}{\partial g^{Cal}} = 1$ then $MEB^f = 100$ which thereby leads to a standard at 2.51 gallons per 100 miles. To justify the 2016 standard of 2.8 requires having $\frac{\partial g^{RUSC}}{\partial g^{Cal}} = 0.56$ or equivalently that 56% of the rest of the US and Canada adopt the Californian standards. Recall that, before the adoption of the Californian objective by the Obama administration in 2009, 16 US States and Canadian Provinces, representing about half of the population, have announced that they would adopt the California norms. Consequently, a third observation we can make is the following: *having an impact on the out of State fuel efficiency may be one of the factor explaining the Californian policy*. Note that MEB^f may even be larger if the Californian standards

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[17] Obviously if every region takes into account the world damage, we could end-up with an over-production of the public good.

[18] *MFCS* justifies a fuel rating of 3.24.

succeed in having an effect, even a small one, on the fuel economy of new cars sold outside North America.[19]

Obviously, cost interdependency is certainly not the only aspect explaining that the rest of the US and Canada has followed the Californian leadership. Political economy arguments could also be invoked like the influence of green pressure groups or the different distributional consequences of these standards.[20] Furthermore, Californian adoption of GHG standards could have been motivated in part by local air pollution concerns as several areas in California do not meet Federal standards.[21] Also, while we have focused our analysis on the cost interdependency caused by R&D, other factors could generate cost interactions such as economies of scale in production as we discuss further in the conclusion.

Another important issue that is not included in our illustration is the risk of carbon leakage if different standards were to be imposed at the State and Federal level as Goulder *et al.* (2010) has demonstrated. Indeed, stricter standards in California may be met by increasing sales of the most efficient vehicles in that State with the unintended consequence of relaxing the Federal constraint elsewhere thereby allowing the increase of less efficient vehicles sales in the rest of the country.

As mentioned previously, the impact of the Californian initiatives on other governments' policies (and on the car industry) rests upon the credibility of the imposed targets. The regulation may fail if the industry feels that the targets are renegotiable. The

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[19] Based on figures reported by Wikipedia, an estimated 19.4 million new automobiles were sold in the US and Canada in 2007 and 52.5 million in the rest of the world.

[20] See Holland et *al.* 2011 for empirical evidence of the impact of distributional impacts on transportation policies in the US.

[21] We thank an anonymous referee for pointing out this aspect.

classical example of this problem is the California effort in the 1990's to reduce air pollution by imposing market-share objectives for zero-emission vehicles (ZEV) (*i.e.* electric vehicles). This strategy to force technology was unsuccessful and the targets were renegotiated several times and strongly diluted (see National Academy of Science, 2006). While this outcome cannot be completely excluded for the GHG regulation, it is important to note that the emission reduction targets could be achieved with technologies that are already used in some vehicles (see National Research Council, 2002).

IV. Conclusions

Increasing energy taxes has long been advocated by economists as one of the most efficient way to deal with external costs associated with energy consumption. Still, most jurisdictions adopt policies that use various other instruments to boost energy efficiency such as standards or feebates. While the absence of political support for increasing energy taxes is certainly a key factor, we show in this paper that the lack of coordination across jurisdictions combined with cost interdependence in the appliance markets could also justify this situation. Indeed, we show using a simple two regions model that the lack of coordination leads to under-taxation of energy. This pushes each region to use the cost interaction to counter the under-taxation of the environmental externality. Indeed, each region adopts energy efficiency policies taking into account that it also affects the marginal cost of increasing energy efficiency abroad. In our model, the cost interdependency results from R&D activities. In other words, a region that adopts a policy that stimulates innovation in the appliance market takes into account that this leads also to an increase in the energy efficiency abroad which in turns reduces environmental damage. The impact on foreign emissions may occur because of adjustments either in the appliance industry or in the energy efficiency policy adopted abroad. For example, we show that in a sequential setting, a more ambitious energy efficiency standard by the leading region may stimulate the following region to also adopt more ambitious standards. As our numerical example has illustrated, even a small impact on the energy efficiency of appliances sold abroad could be meaningful if it concerns a large stock.

Other factors could also generate cost interdependencies such as economies of scale, economies of scope or learning by doing in energy saving technologies. Indeed, these cost interactions also create a way for one region to affect emissions produced abroad. Obviously, the resulting policy parameters will vary depending upon the details of the cost interactions.

In our model, we have assumed away market power distortions. Adding this aspect would certainly be interesting but it is unlikely to affect the main conclusions of our analysis. Indeed, even with market power, it is very likely that the equilibrium energy efficiency will depend upon the marginal cost of offering more efficient appliances. Policies in one region should therefore still have an impact on the other region's appliance performance when there are cost interactions. Also the type of effects underlined in this paper remains relevant if the cost interactions are not fully internalized by the industry. For example, if each region has its own domestic appliance industry that invests in R&D with spillovers effects in the other region. Obviously, if there are R&D spillovers, achieving the first best will require stimulating innovation. However, in the uncoordinated outcome, the under-taxation should still be present and so does the incentive to reduce foreign emissions. In this case however, other well-known effects will also operate such as the incentive for each region to free ride on the R&D activities of other regions.

In future work, it would certainly be interesting to explicitly model the appliance manufacturers' reaction in terms of prices, sales, design and innovation. Clearly, the size of the regions adopting energy efficiency targets is likely to have an impact on the manufacturers' response. If the region adopting the energy efficiency target is only a small market, manufacturers may react by simply shifting sales to more efficient existing models (for example smaller cars). If a large market is at stake, they are more likely to look for innovative solutions.

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